AL/CF-SR-1995-0016

ASSESSMENT OF NECK MUSCLE BIODYNAMICS DURING IMPACT

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August 1993

Final Report for period of July 1990 to August 1993

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NOTICES

TECHNICAL REVIEW AND APPROVAL

AL/CF-SR-1995-0016

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE DIRECTOR

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Air Force Research Laboratory

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	Aug 1993	Final - July 1990 to August 1993

4. TITLE AND SUBTITLE

Assessment of Neck Muscle Biodynamics During Impact

5. FUNDING NUMBERS

PE - 61101F
PR - ILIR
TA - BB
WU - 03

6. AUTHOR(S)

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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2800 Q Street, Bldg 824
Wright-Patterson AFB OH 45433-7947

8. PERFORMING ORGANIZATION REPORT NUMBER

AL/CF-SR-1995-0016

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

An experimental effort was conducted to assess the neck muscle's biodynamic characteristics using electromyographic (EMG) data collected during a human impact study. EMG data were collected from specific neck muscles of volunteer human subjects before, during, and after the subject was exposed to a vertical impact. Data analysis consisted of the Integrated Threshold Detector method, and then using the integrated EMG to determine muscle recruitment patterns and frequency distributions. The only definite conclusion that can be made from the results of this study is that EMG data can be collected during a simulated aircraft ejection. Interpretation of these data is not fully understood; however, some trends were observed. The higher the acceleration level of the test, the higher the magnitude of the EMG rectified mean value. The linear fit of the pre-impact voluntary isometric contractions is quite good in most cases. There appears to be a greater range in the EMG rectified mean values for the trapesius muscles during the backward voluntary contractions and similarly for the sternocleidomastoid muscles during the forward voluntary contractions. Additional EMG research is required.

14. SUBJECT TERMS

vertical impact, EMG, maximum voluntary contraction (MVC)

15. NUMBER OF PAGES 29

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

Standard Form 298 (Rev. 2-89) (EG)
Prescribed by ANSI Std. 239.18
Designed using Perform Pro, WHS/DIOR, Oct 94

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PREFACE

An experimental effort was conducted to assess the neck muscle's biodynamic characteristics using electromyographic (EMG) data collected during a human impact study. EMG data was collected from specific neck muscles of volunteer human subjects before, during, and after the subject was exposed to a vertical impact. Data analysis consisted of the Integrated Threshold Detector method, and then using the integrated EMG to determine muscle recruitment patterns and frequency distributions. The vertical impact tests and EMG data collection and analysis described in this report were accomplished by the Crew Protection Branch and the Modeling and Analysis Branch, Human Systems Division, Harry G. Armstrong Aerospace Medical Research Laboratory (AAMRL/BBP and AARML/BBM). Test facility and technical support were provided by DynCorp, Inc. under contract F33615-91-C-0531.

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INTRODUCTION

Abrupt impacts expose the head and spine to intensive loading conditions that can cause paralysis or even death. United States Air Force experience also shows an extremely high incidence of minor neck muscle injury including sprains and strains, and a less frequent incidence of major and fatal trauma to the neck such as fracture, dislocation, and spinal cord impairment, as a result of ejection from aircraft. From 1978 to 1988, there were 276 incidents of neck injury during ejection from United States Air Force trainers and fighters (10).

The scientific community needs a better understanding of the neck's dynamic biomechanical characteristics to effectively evaluate cervical spine injury protection methodologies. Acceptable head/neck impact loading tolerance levels need to be defined as a result of the use of helmet-mounted visually coupled systems. This is particularly important as these helmet mounted systems can impose increased loads on the neck during the catapult phase of ejection.

Some previous studies of the neck's response characteristics have dealt with fatigue and voluntary isometric contractions as defined using electromyography (EMG) data (6,7,8). Additional research was conducted to measure neck muscle EMG during simulated car crashes. This data indicated that neck muscle reflex times range from 54-92 ms; however, there was no attempt to quantify the muscle activity during impact as compared to static loading (4). Very little research has been completed examining these parameters before, during, and after an impact.

METHODOLOGY

Experimental Design

The purpose of this research was to study the EMG signal collected from the right and left sternocleidomastoid and trapezius muscles of the neck (Figure 1) before, during, and after vertical impact. The study used three vertical impact acceleration levels of 6, 8 and 10 G. The volunteer human test subjects wore two helmets, the HGU-26/P and the HGU-55/P, during the series of impact tests. Each helmet was tested with an MBU-12/P oxygen mask. These helmets are presently found in the Air Force inventory. The test matrix is shown in Table 1.

Table 1. Test Matrix

Impact Accel. (G)	HGU-55/P	HGU-26/P
6	A1	B1
8	A2	B2
10		B3

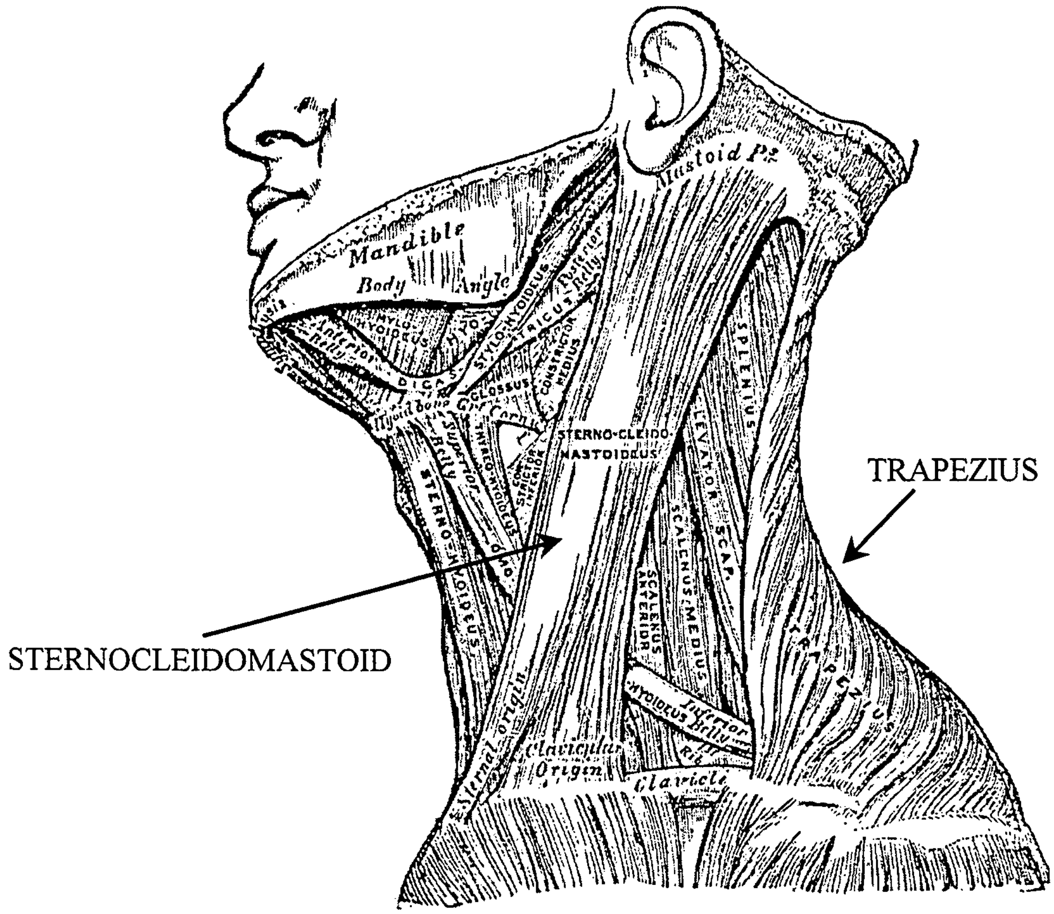

Figure 1. Sketch Showing Neck Muscles Used for EMG Analysis (Left Side Only)

EMG is the measurement of the electrical activity caused by complex biochemical reactions that occur in the muscle and surrounding area during muscle contraction. When nerve impulses sent from the brain tell the muscle to contract there is a transport of ions between the muscle cell's outer and inner membrane creating an electromagnetic field, which rapidly moves along the muscle fiber as a result of the depolarization. This field creates a voltage called the muscle fiber action potential, which electrodes can detect.

There are several ways to perform this voltage measurement using electrodes. The most accurate way involves inserting a needle electrode directly into the muscle fiber of choice and measuring the activity present. This method enables one to measure the action potentials produced by single motor units of the muscle. However, this is an invasive procedure and must be done with extreme care. A less accurate, but much easier and less painful implementation uses surface electrodes affixed to the skin over the muscle groups of choice. Since the size of these electrodes is much larger than the individual motor units, each electrode does not measure the activity of a single unit but rather a summation of the activity of all the motor units in the region of the muscle located under the electrode.

The measured EMG signal is similar in characteristics to zero mean filtered white noise and over short time segments the EMG can be considered to be a stationary process. The EMG time history reveals information about the activity of the muscle. The number of motor units recruited in generating the force of contraction, as well as their rate of discharge, influences the amplitude of the EMG signal. Previous research has established that the amplitude of the electromyogram, and the tension or force developed in brief isometric contractions, is generally linear (7,8).

The subjects that participated in the experimental tests were active duty military members of the AAMRL Impact Acceleration Stress Panel. Participation on the panel is completely voluntary and required a complete physical examination with a thorough screening for any spinal abnormalities. The test subjects used for the analyses in this paper were all male subjects. A summary of select anthropometric parameters is shown in Table 2.

Table 2. Human Subject Anthropometry

Subject ID	Weight (lb)	Height (in)	Sitting Height (in)
B1	172	70.5	37.0
B9	155	69.0	34.5
C7	150	67.0	34.0
L8	185	71.0	35.0
L9	160	71.0	36.0
T6	185	69.5	36.5

All of the impact tests were conducted on the Vertical Deceleration Tower (VDT) facility located in the Escape and Impact Protection Branch of the Armstrong Laboratory at Wright-Patterson AFB. A four-point restraint harness consisting of double shoulder straps and a lap belt secured the test subjects during the tests on the VDT. The seatback was fully upright at 0 degrees for all of the impact tests.

As indicated previously, the investigators chose the right and left sternocleidomastoids as two of the muscles used for EMG measurements. These muscles are large muscles located on respective sides of the neck running from behind the jaw to near the clavicle as Figure 1 shows. This muscle pair was chosen because it is located close to the skin surface and is relatively easy to locate for proper electrode placement. When the test subject turned his head to the right or left, the sternocleidomastoid muscle on the opposite side of the neck could easily be seen. The investigators also chose to study the response of the right and left trapezius muscles. These muscles are located at the back of the neck extending downward across the tops of the shoulders as Figure 1 shows. The investigators were able to locate these muscles both visually and by palpation.

Before taking any EMG measurements, the test conductors had to prepare the skin covering the sternocleidomastoid and trapezius muscles. Normally skin has a resistance in excess of 50 kohms. To collect an EMG signal this resistance must be reduced. First, the test conductor used a razor to remove any hair present on the neck, and then wiped the skin with an alcohol pad to remove any loose dead skin particles, oil, or dirt from the surface. The skin was then rubbed vigorously with a fine grade of sand paper to roughen the surface and abrade any excess dead skin cell which increase resistance. The test areas were then wiped with a gauze pad to remove the particles of grit and dead skin cells loosened by the sanding process. Solid adhesive gel (disposable) Ag/AgCl bipolar electrodes were then affixed to the test areas. The test conductor placed two electrodes approximately two inches apart on each muscle group on the right and left sides of the neck. The application to the left side of one subject is shown in Figure 2.

The subject was then positioned in the maximum voluntary contraction measurement fixture built similar to one used by Petrofsky and Phillips (5,9). The test apparatus consisted of a specially designed rigid metal frame, an adjustable seat, and a helmet fixed to the frame as shown in Figure 3. A load cell, attached to the helmet, measured the force generated by the test subject during each voluntary isometric contraction.

Figure 2. Location of EMG Surface Electrodes on Left Side of Volunteer Subject

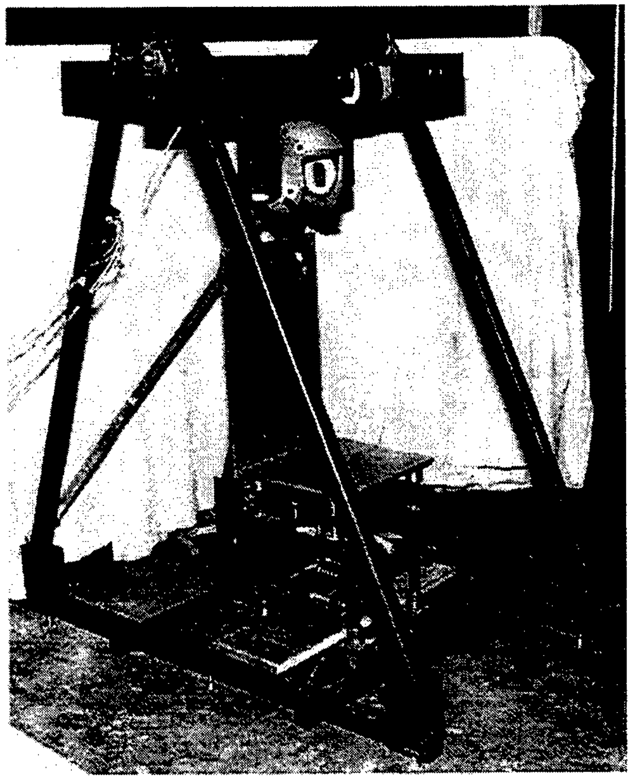

Figure 3. Maximum Voluntary Contraction Measurement Fixture

Once the subject sat in the seat, it was adjusted such that the helmet fit comfortably on his head. This involved both raising or lowering the seat, as well as forward or backward adjustment. When the subject was comfortable he securely fastened the lap belt restraint and the helmet chin strap. At this point the test conductor measured the skin resistance at each of the eight electrodes. If the measured resistance was above 2 kohm the test conductor removed the electrodes and again prepared the skin. This was necessary in order to eliminate the potential for motion artifact. Usually, however, the measured resistance was less than 2 kohms. The subject positioned in the MVC fixture is shown in Figure 4.

A 14 pin connector attached the electrode cables to the data acquisition system. A voltmeter was connected to the load cell. This instrument displayed the force generated by the test subject as he performed forward and backward voluntary contractions by pushing his head against the front and back of the helmet.

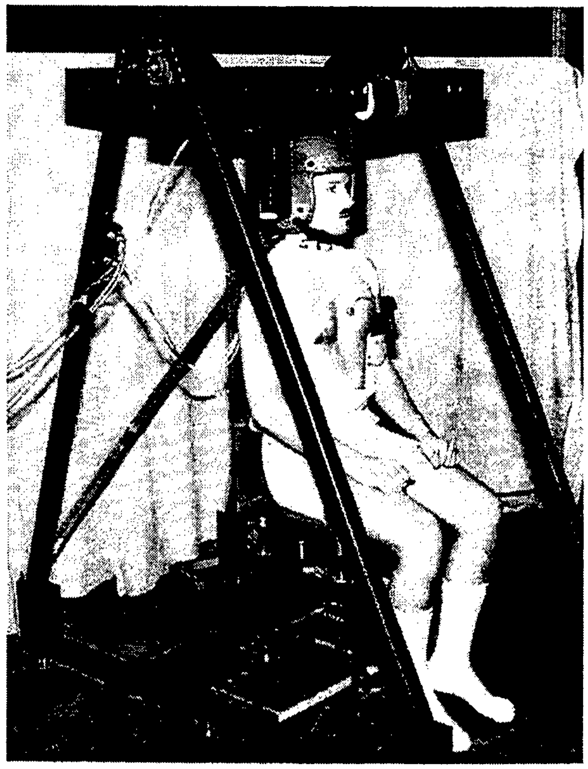

Figure 4. Maximum Voluntary Contraction Measurement Fixture with Test Subject

Test Procedure

The test proceeded as follows. The first test performed by the test subject was the 100% pre-test forward maximum voluntary contraction (MVC). For this test the subject generated as much force as he could in pushing against the front of the helmet. The subject was to use only his neck muscles to do the pushing. He kept his hands resting loosely in his lap. The test conductors monitored the tests very closely to insure that the subject generated the measured force using only his neck muscles. When the instrumentation room was ready, the test conductor told the test subject to begin pushing. When the voltmeter readout had stabilized at a maximum, the test conductor counted, 'Three, two, one, hold,' instructed the subject to hold that force level, and then pressed the event marker switch. The subject held this maximum contraction as steady as possible for three seconds. He was able to see the voltmeter, which helped him to maintain a constant force. After three seconds, the test conductor told the subject to release the force. The test subject was then able to relax for several minutes before performing the next EMG measurement test. Meanwhile, the test conductor calculated the voltage measurement required for the 50% pre-test maximum voluntary contraction.

The test subject performed the 50% pre-test maximum voluntary contractions in the same manner as the 100% pre-test MVC measurement. For these tests, however, the subject knew what voltage to try to attain on the voltmeter in order to be at 50% of his MVC. When the subject reached that level, he again maintained that force for three seconds while the EMG data was collected. The test subject repeated the process for the backward voluntary contractions. In some cases, the subject also performed 75% and 25% MVC tests.

The subject then proceeded to the Vertical Deceleration Tower to participate in a vertical impact test. For this, test the subject, seated in the modified ejection seat on a platform, was raised to a predetermined height. After a countdown the platform was released to free-fall. The impact occurred when the pin at the bottom of the carriage plunged into a water-filled reservoir. The pin and the height from which the platform was released determined the impact acceleration pulse shape. All acceleration levels used in these tests were at sub-injury thresholds.

After each impact, the medical monitor examined the subject while still positioned in the VDT seat. The subject then was allowed to continue the neck muscle measurements on the MVC test fixture. The subject again fastened himself in the seat using the lap belt; he also fastened the chin strap on the helmet. The electrode cables were connected to the data acquisition system. The subject then performed the 100% maximum voluntary contraction in the forward and backward directions exactly as before. He was not able to see the voltmeter since doing so may have influenced his effort.

The EMG signals, the forces exerted by the neck muscles and the event markers were recorded on magnetic tape. The data acquisition system filtered the data at 1200 Hz and sampled the data at 5000 Hz. Since the typical EMG signal is in the 20 to 500 microvolt range, a differential amplifier with large input impedance pre-amplified the signal before it entered the data acquisition system. The signal was very sensitive to electronic noise, but by shielding the electrodes and locating the amplifier near the data collection points, these problem were kept minimal.

RESULTS

The VAX 11-750 computer divided the collected EMG signals for each test into 60 msec segments and then rectified and integrated these segments. The mean value of these segments was then calculated for each test configuration for each subject. This mean value was plotted on a graph of EMG rectified mean vs mean head load measured during the maximum voluntary isometric contraction. The data from the pre-impact isometric maximum voluntary contractions appear as "+" symbols, and the post-impact isometric maximum voluntary contractions appear as "x" symbols. The tests did not use a load cell to measure the force generated by the neck muscles during the actual impact. Therefore, there is no way to plot the EMG rectified mean data as points on these graphs. The data are instead plotted as horizontal lines determined by the values obtained for the EMG rectified mean data. A graphics software package performed a best fit linear regression on each of the graphs for the pre-impact isometric contraction data. The graphs show the correlation values for each case. Figures 5 and 6 are examples of the types of data plots that were generated for this data analysis for subject B1. Data plots for the remaining subjects are located in Appendix A.

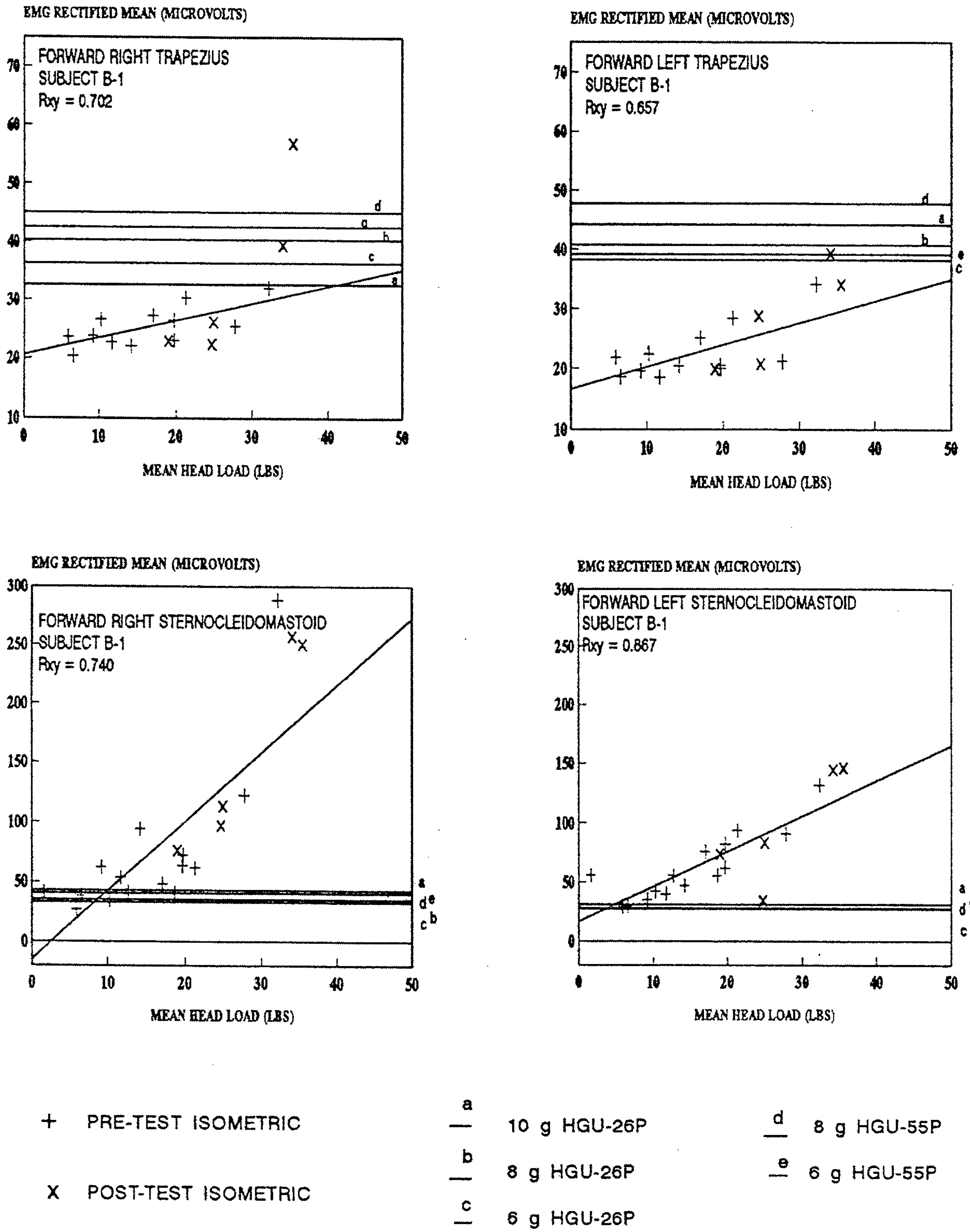

Figure 5. EMG Rectified Mean Versus Mean Head Load for Subject B1 Forward Muscle Force Measurement

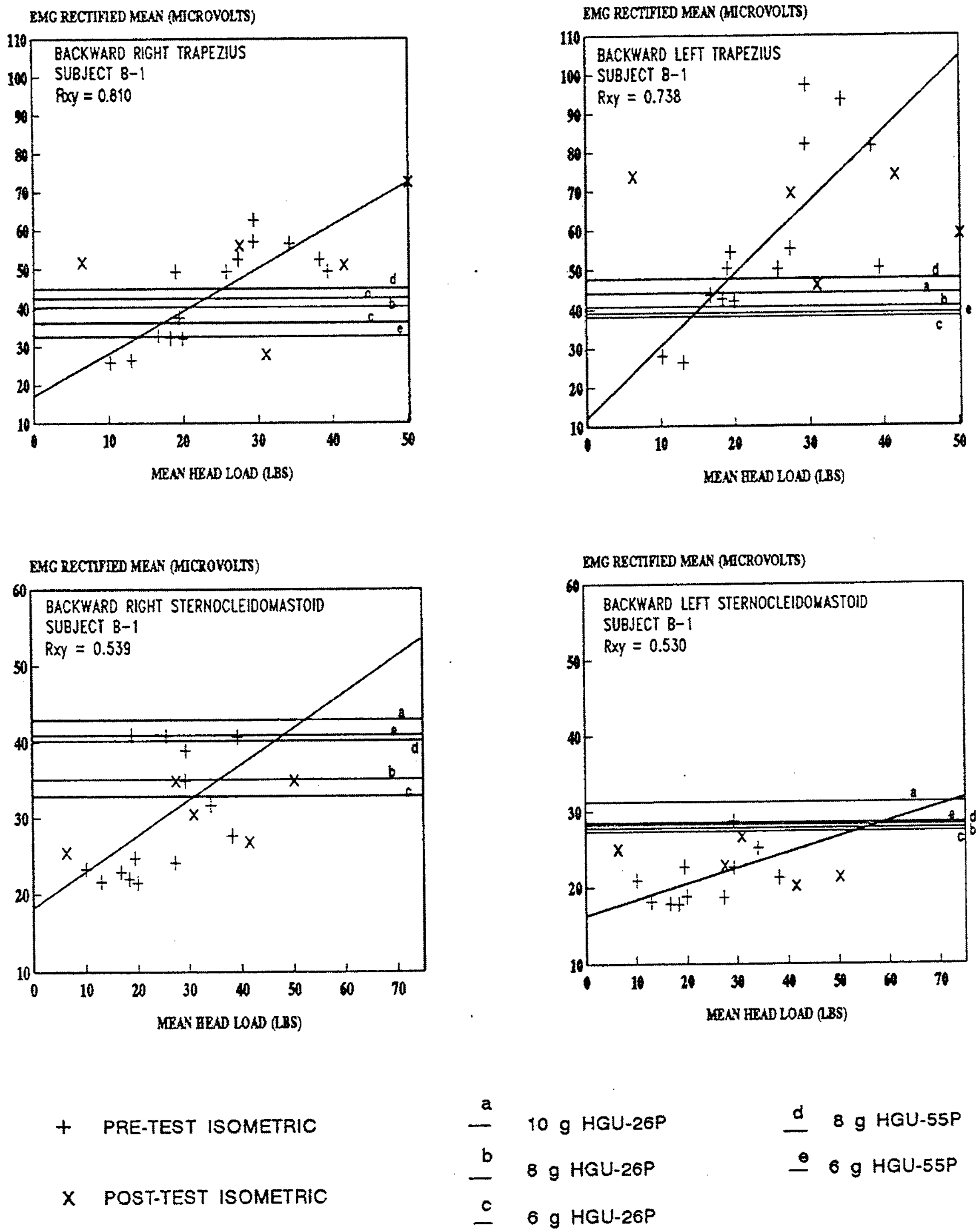

Figure 6. EMG Rectified Mean Versus Mean Head Load for Subject B1 Rearward Muscle Force Measurement

Many trends were observed in several of the tests. One such trend is that generally the higher the acceleration level of the test, the higher the magnitude of the EMG rectified mean value. The linear fit of the pre-impact voluntary isometric contractions is quite good in most cases. There appears to be a greater range in the EMG rectified mean values for the trapezius muscles during the backward voluntary contractions and similarly for the sternocleidomastoid muscles during the forward voluntary contractions.

There was however no significant trend as to whether the HGU-55/P or the HGU-26/P helmets made a difference on the EMG measurements. In some cases tests at 8 g using the HGU-55/P helmet resulted in higher EMG rectified mean values than tests at 10 g using the HGU-26/P helmet; in other cases the reverse was true. In some tests the EMG rectified mean values fall within the range observed during the isometric voluntary contractions; in other tests, this is not the case.

The test conductors assumed that the right and left side EMG measurements of each muscle group would be very similar. The data did not show this to be true in all cases. This could be attributed to several things such as poor symmetry in electrode placement, poor subject position during the EMG measurement, or actually differences in the neck muscles themselves.

CONCLUSIONS

The only definite conclusion that can be made form the results of this study is that EMG data can be collected during a simulated aircraft ejection. Interpretation of this data is not fully understood; however, some trends were observed.

The test conductors learned many lessons in during the course of the study. These may be of even greater value than the test problem itself, and, therefore, will be explained.

The test conductors were not experts in muscular anatomy. They attempted to locate the trapezius and sternocleidomastoid muscles to the best of their abilities, but this was difficult in some cases.

Each time a subject arrived to participate in an impact test the test conductors places the electrodes on his neck. There was, however, no way to know the exact position of the electrodes in the previous test. This can cause major problems since the data collected is a summation of the muscle activity beneath the electrode. Different areas of the same muscle can give very different measurements, making it difficult (impossible) to compare the data collected form tests conducted on different days if the electrodes are not in the same location. It would be of great benefit to mark the position of the electrodes using a permanent marker so placement of the electrodes is less variable from test to test.

More data needs to be collected during voluntary isometric contractions to determine the amount of variability in the EMG signal. This would help the subjects learn to isolate and use the required muscles in completing the tests. The test conductors would also benefit by learning subtle indications that show that the test subjects are not using the required muscles.

Since the tests took place over a period of two months, it is possible that the physical condition of the neck muscles changed significantly due to exercise or lack thereof. A log of exercise activities may be useful in determining what effect strengthening the neck muscles has on EMG measurements before, during and after the impact. The subjects' heights, weights, and neck circumferences and their EMG measurements could be examined for any possible correlations. Another area for possible further examination may be to study the effect of completing neck muscle stretches before taking the EMG measurements.

The amount of force generated by the neck muscles during the impact should be measured. This help determine where the impact test data point should go on the plot of EMG rectified mean vs mean head load.

The photogrammetric data should be examined to determine the extent of head motion during the impact test. This would show whether or not the EMG data collected may be the result of the head motion itself. EMG measurements should also be made during easily repeated dynamic tests to develop an understanding of the effects of dynamic movement.

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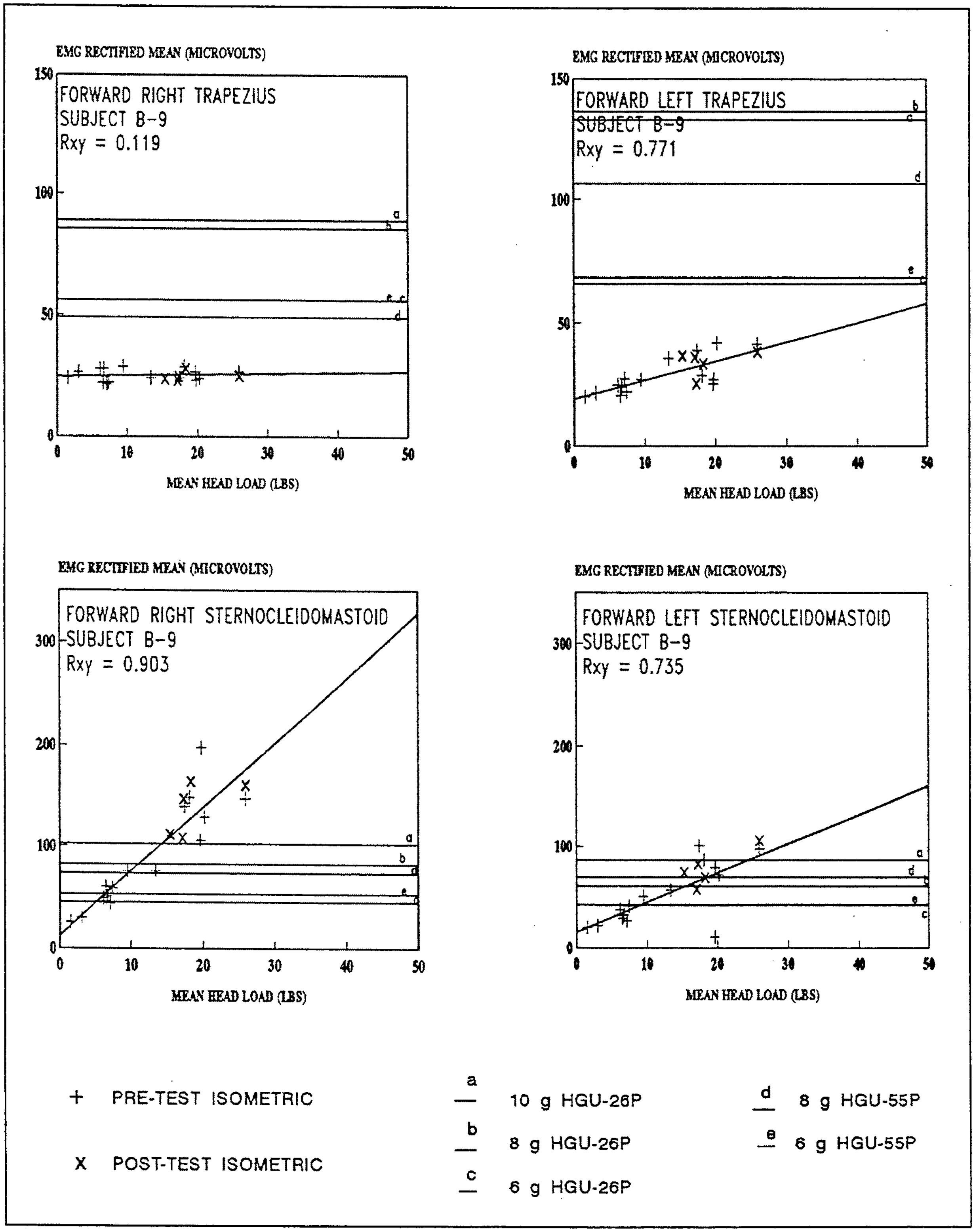
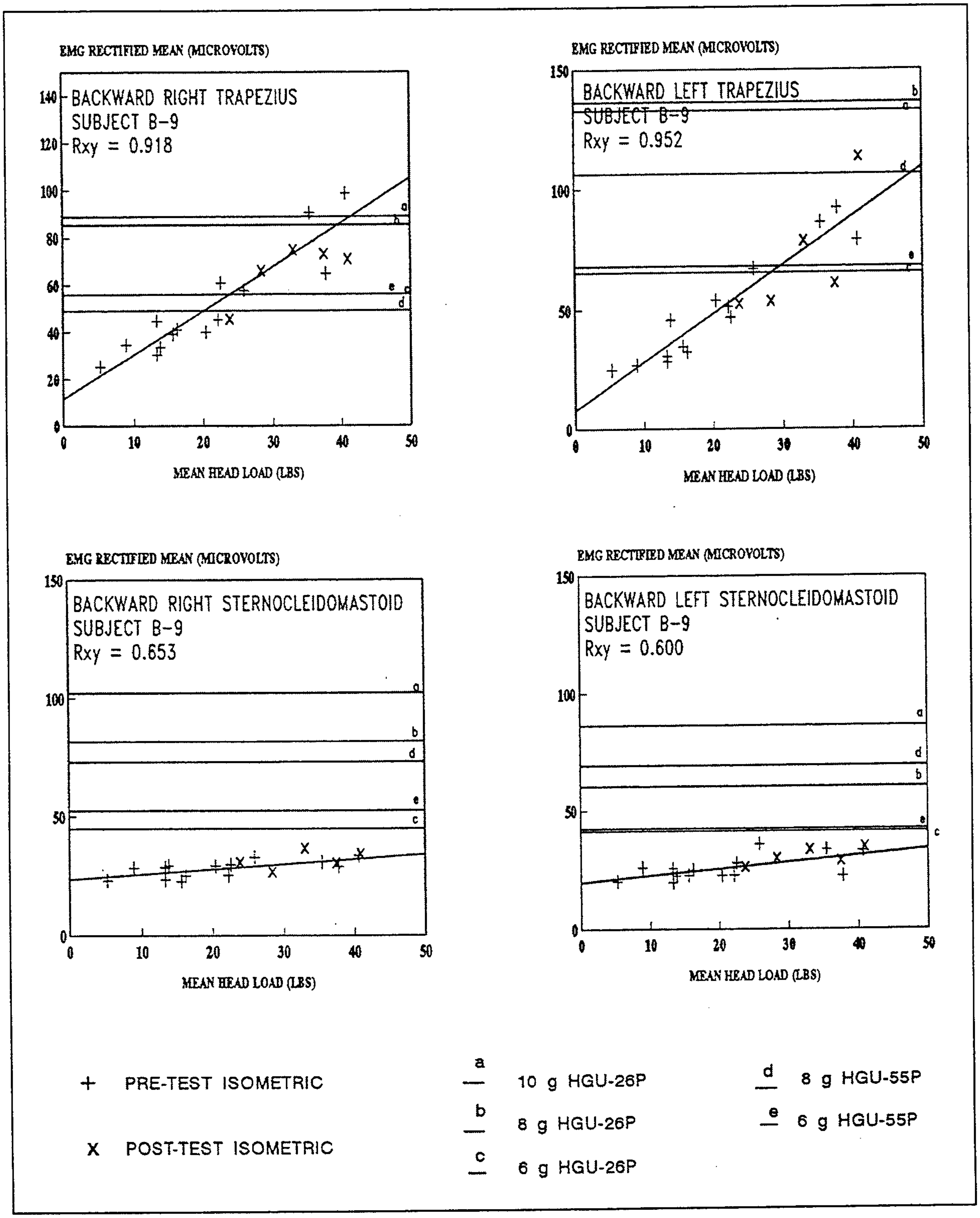
APPENDIX A.

EMG Rectified Mean Versus Mean Head Load Plots for Subjects B9 through T6

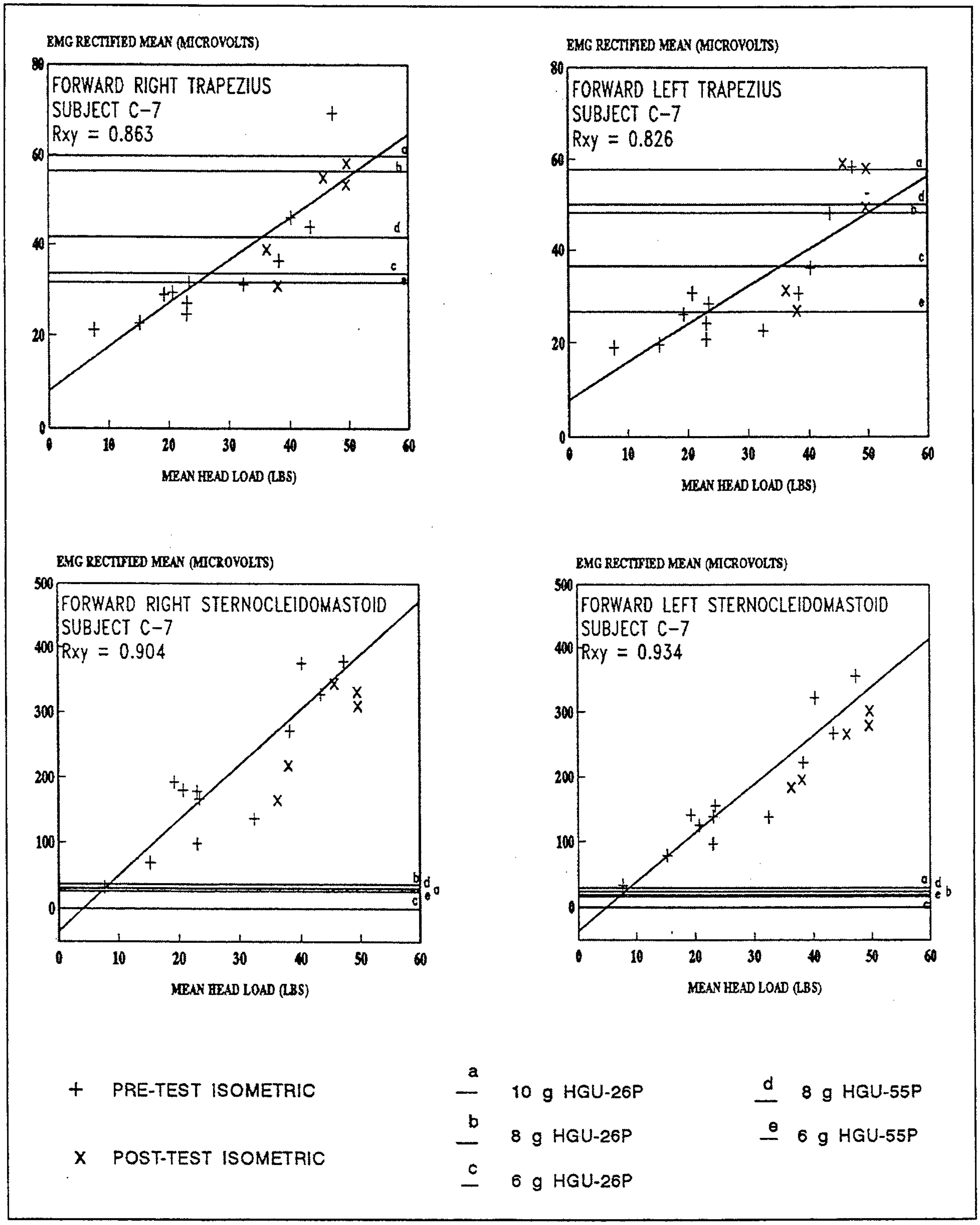
EMG Data for Subject B9: Forward Force



EMG Data for Subject B9: Rearward Force



EMG Data for Subject C7: Forward Force



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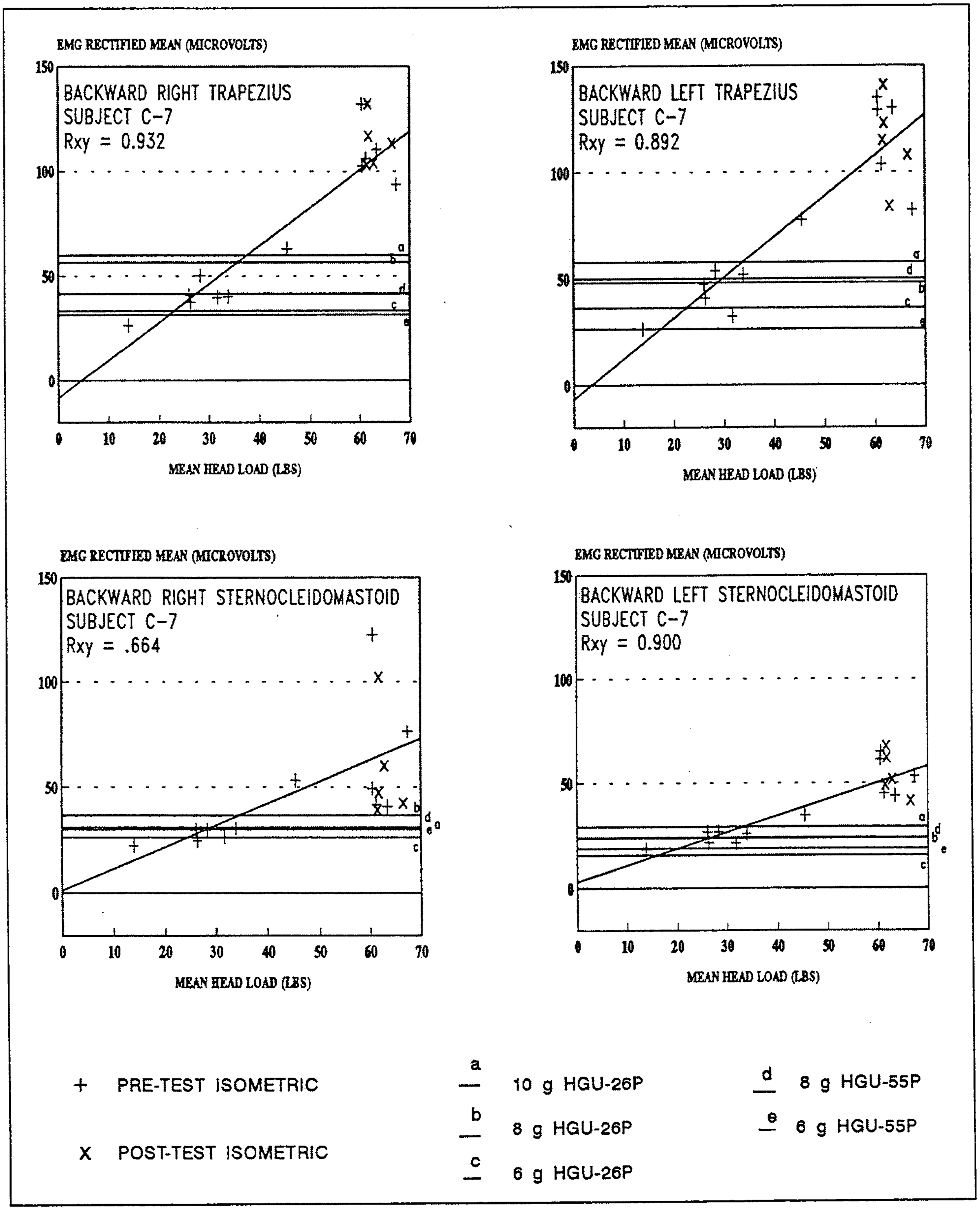
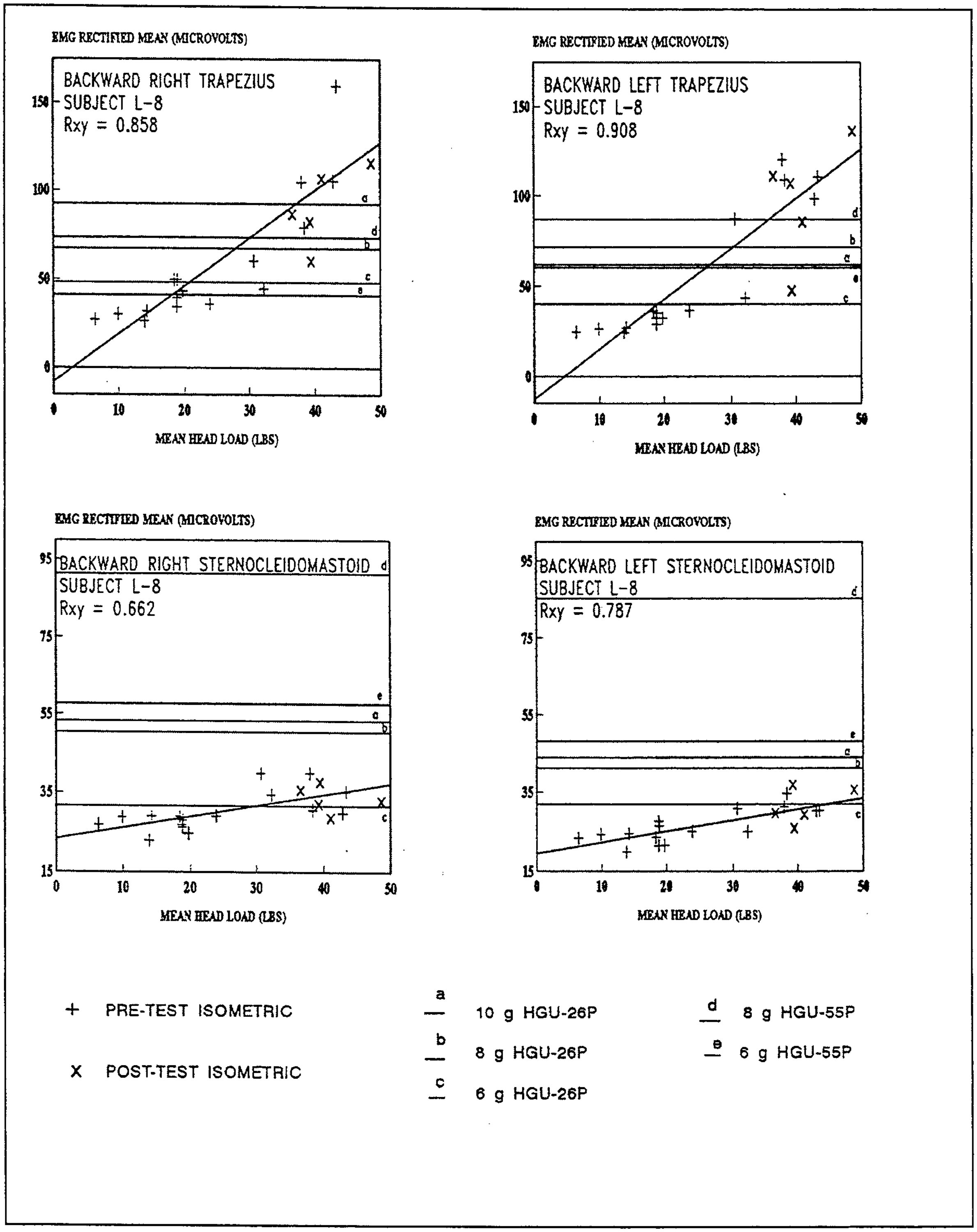
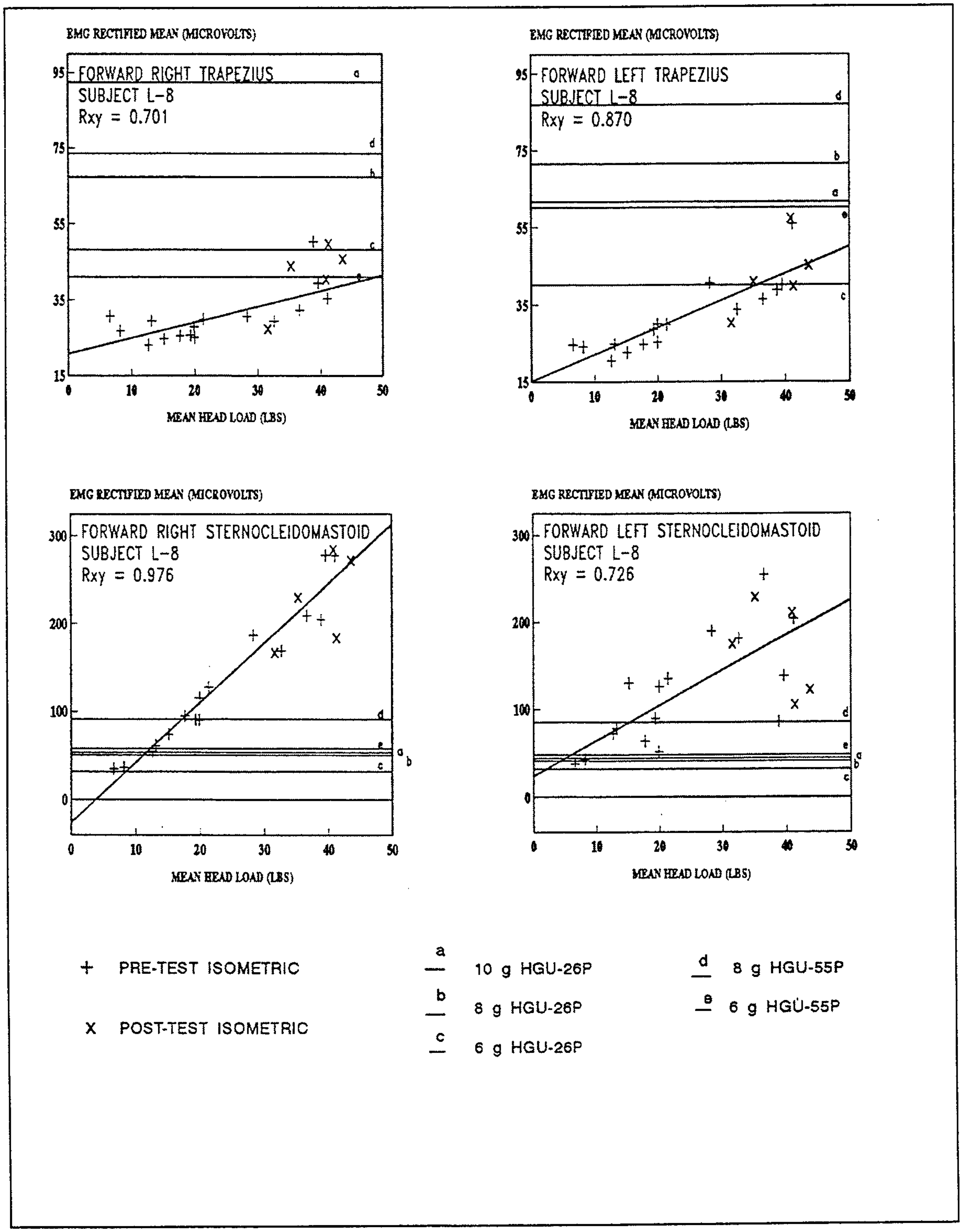


EMG Data for Subject L8: Forward Force



EMG Data for Subject L8: Backwork Force



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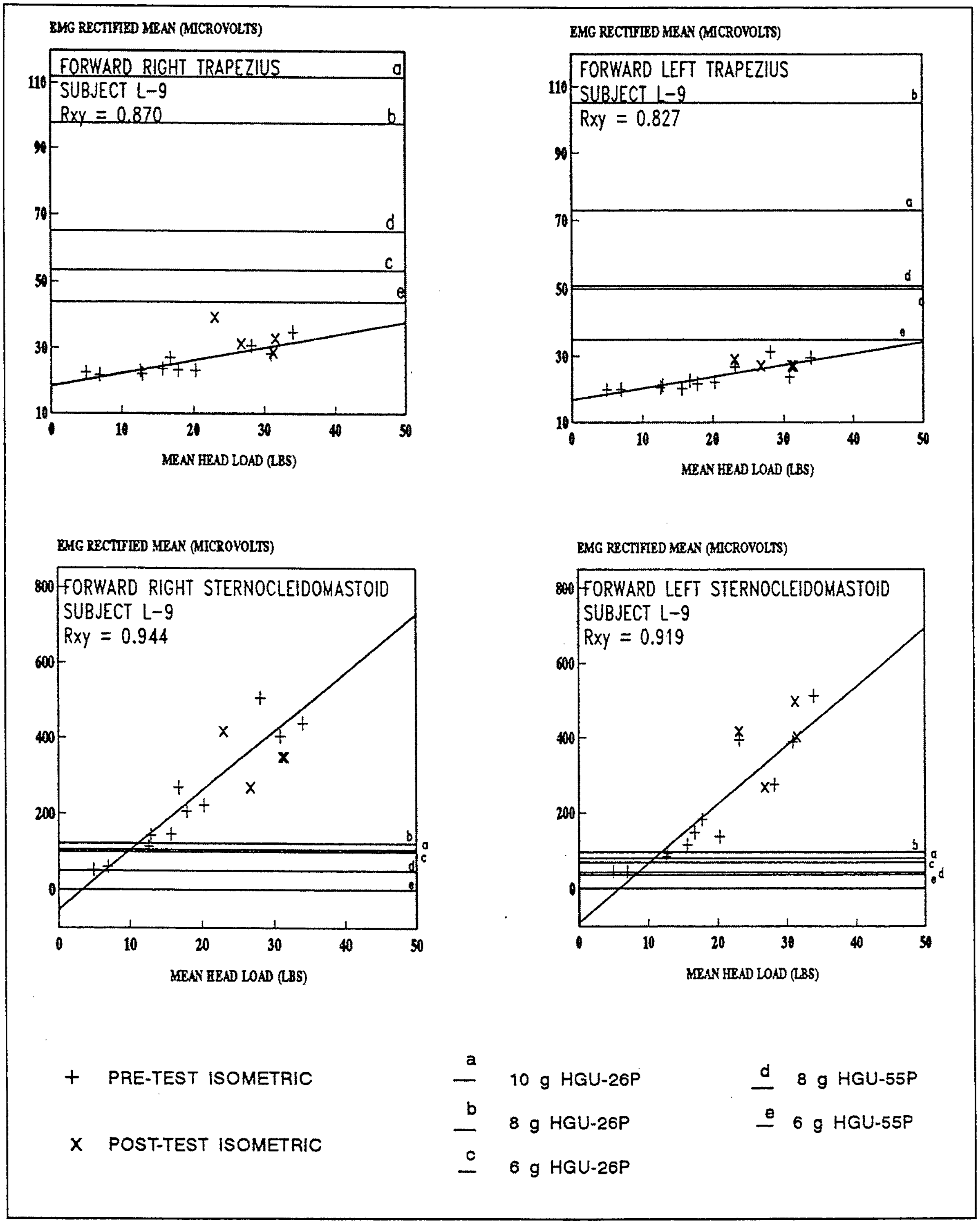
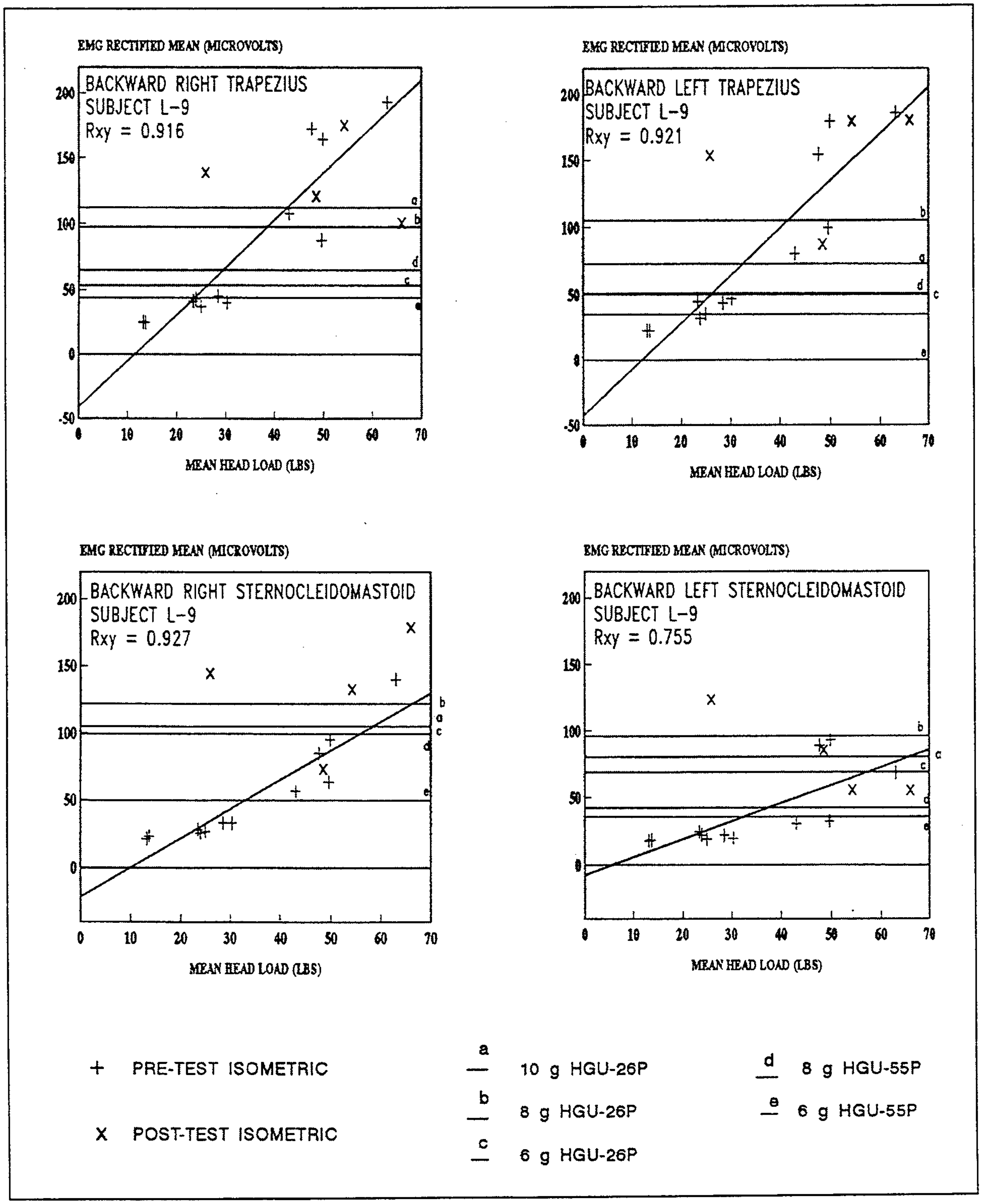
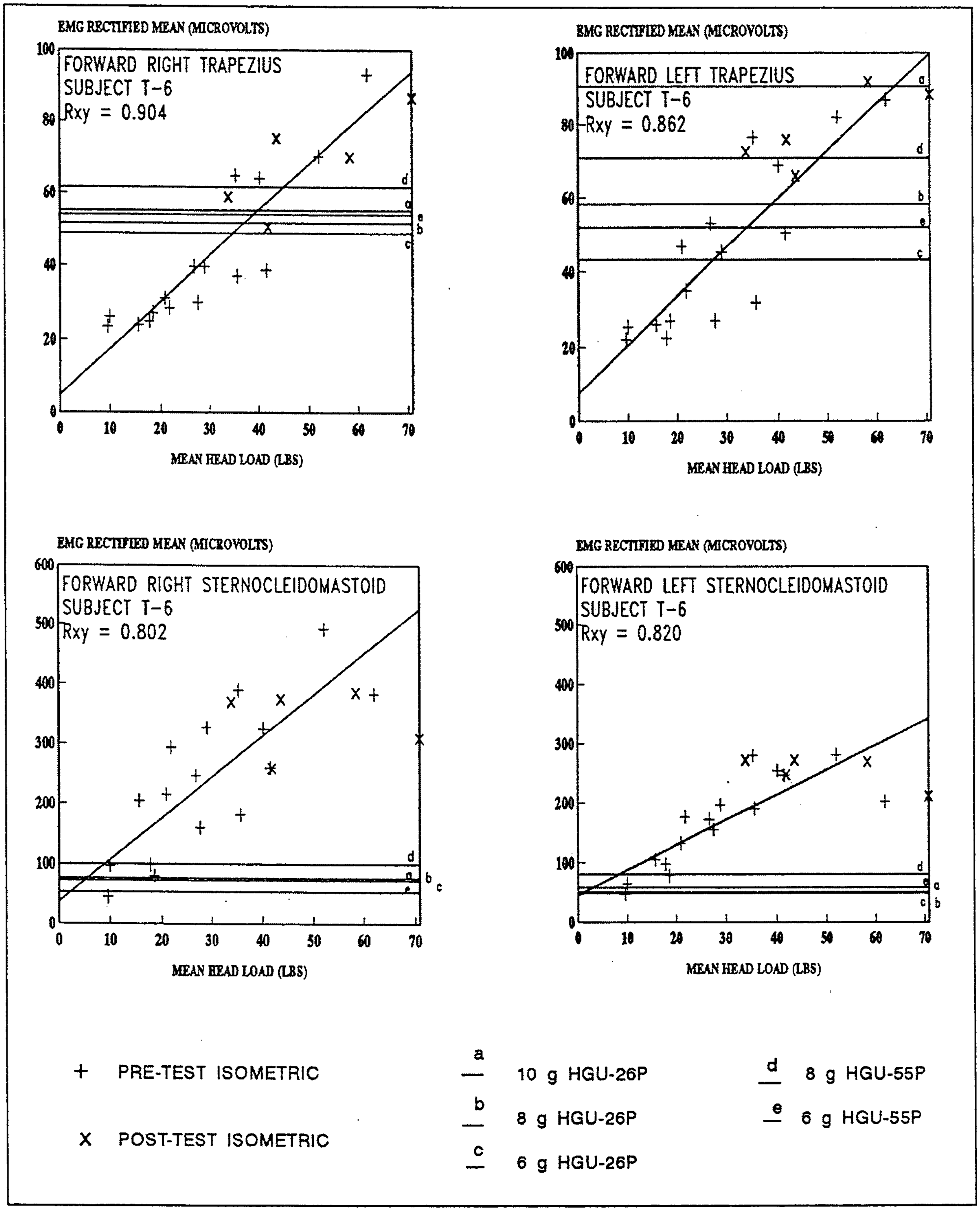


EMG Data for Subject L9: Rearward Force



EMG Data for Subject T6: Forward Force



EMG Data for Subject T6: Rearward Force